Seminario secondo anno

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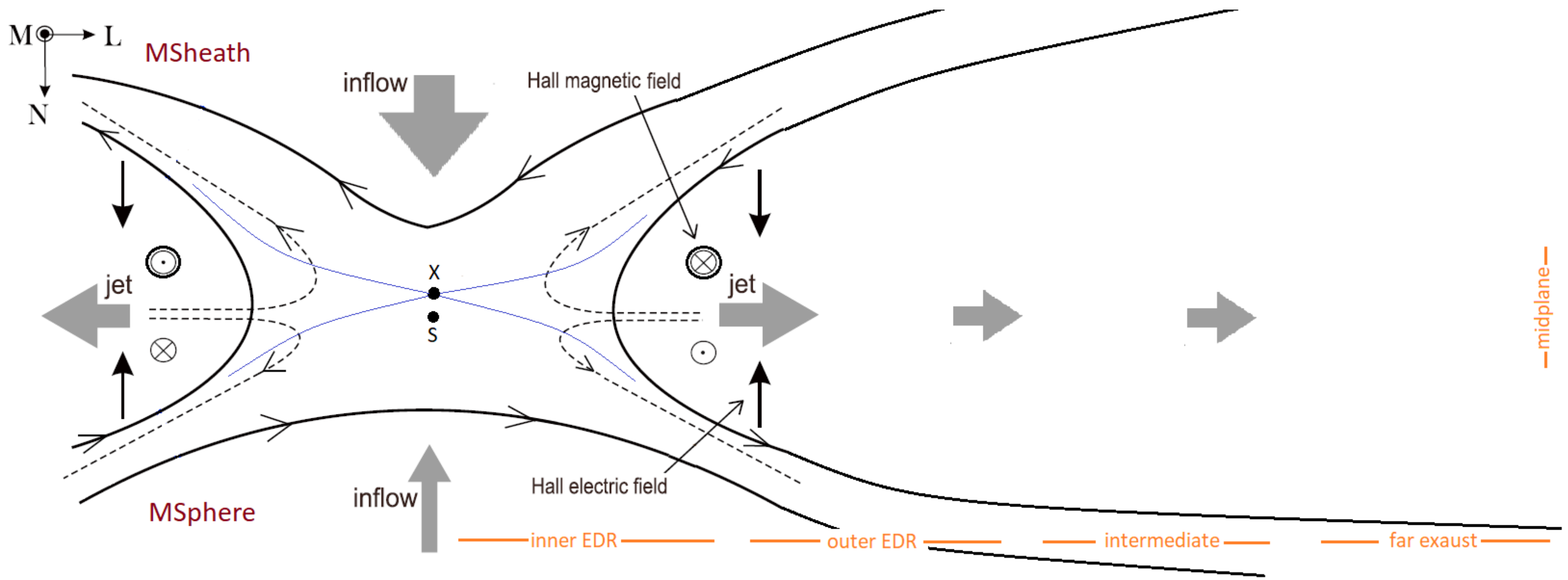
23 September 2019



Magnetic Reconnection

- Practically ubiquitous in plasma physics (fusion devices, large-scale space plasmas, star coronae)
- Complex phenomenon (different effects on electrons and ions, nontrivial spatial pattern)
- Strong dependence on external conditions (various degrees of asymmetry, various guide field strengths)

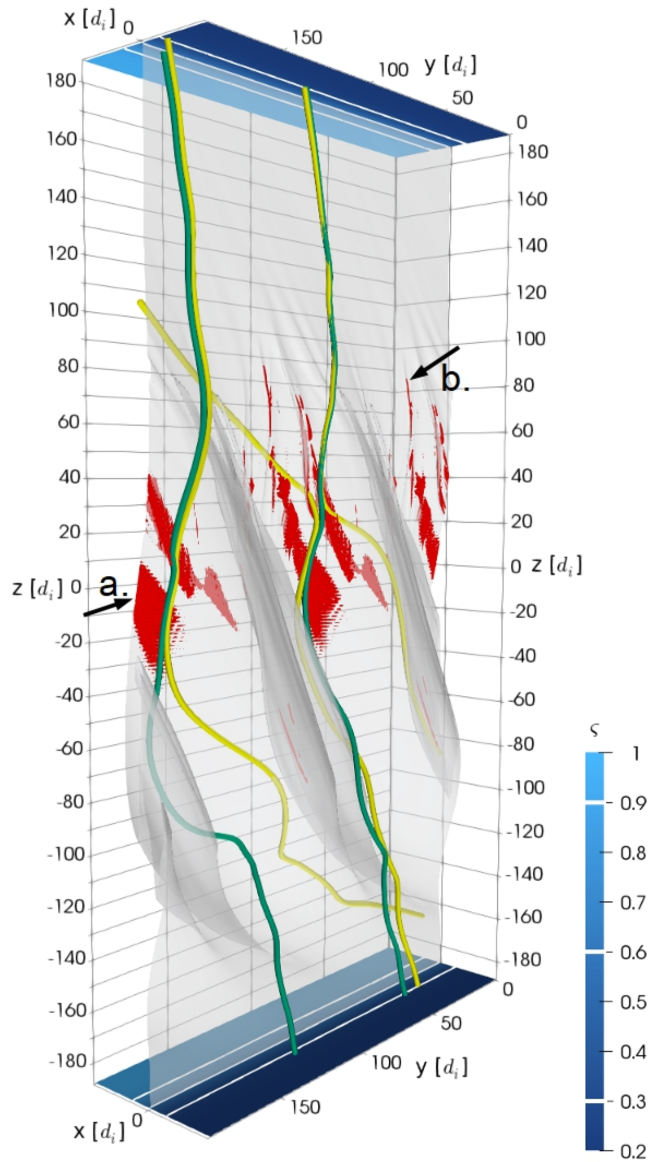
… thesis idea: use MMS observations (Toulouse) & numerical simulations (Pisa) to investigate <u>the microphysics of magnetic reconnection</u>!

... my "background"

North-South Asymmetric Kelvin-Helmholtz Instability and Induced Reconnection at the Earth's Magnetospheric Flanks

Published: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2018JA025626

- Cross-magnetopause transfers of mass and momentum pose a long-standing problem in near-Earth plasma physics
- We perform two-fluid, three-dimensional simulations of magnetopause flanks focusing on latitudinal extent of its perturbations
- Results on non-linear behavior of Kelvin-Helmholtz instabilities and induced reconnection phenomena

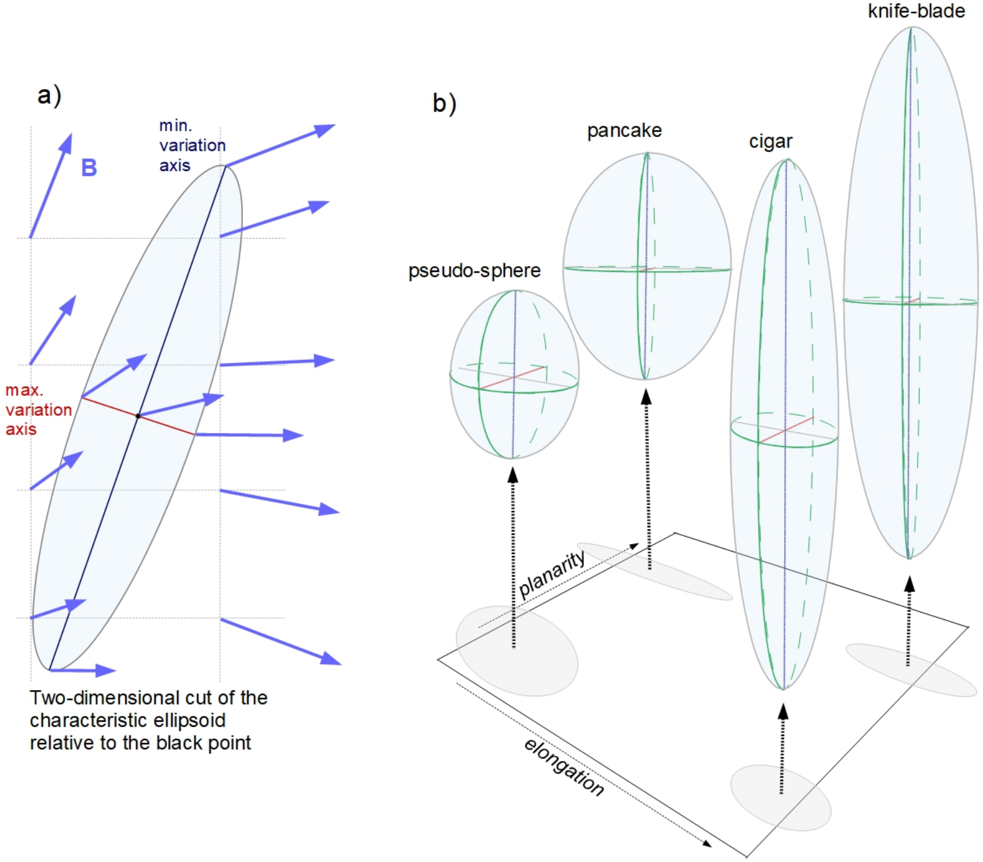


… my first MMS paper!

Four-spacecraft measurements of the shape and dimensionality of magnetic structures in the near-Earth plasma environment

Published: https://doi.org/10.1029/2019JA026747

- Knowing the local behavior of magnetic field is fundamental in all near-Earth plasma physics
- We propose a new method to measure local magnetic configurations and benchmark it on known events: crossings of flux ropes, current sheets, magnetic holes
- From a statistical analysis we retrieve general trends in magnetic shapes through the outer magnetosphere, magnetosheath and near-Earth solar wind



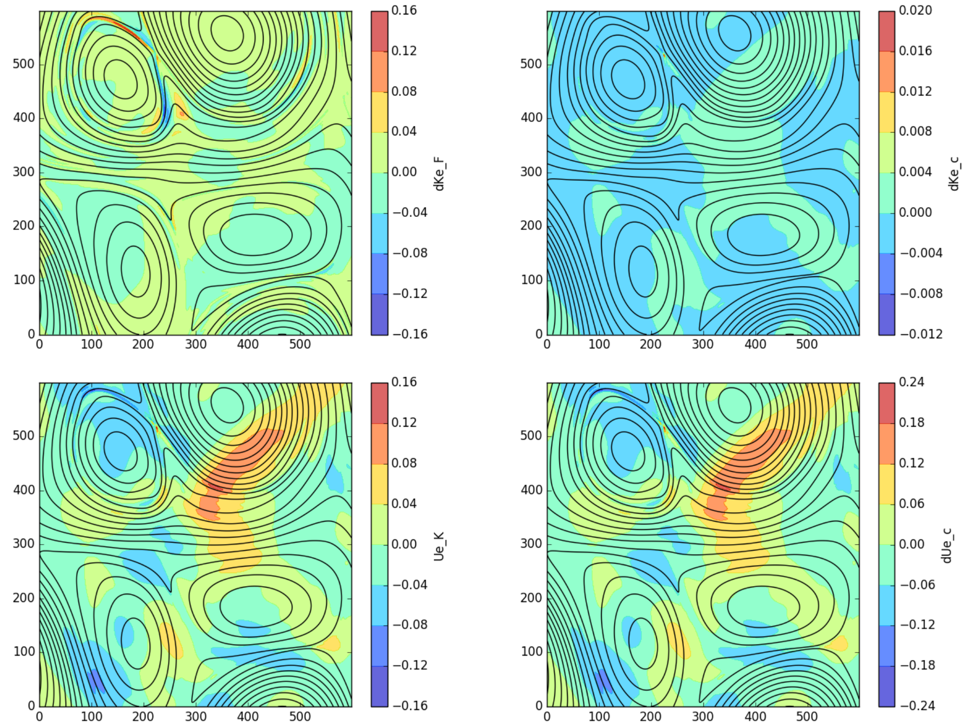
Two-dimensional cut of the characteristic ellipsoid relative to the black point

… ongoing studies!

Microphysics of reconnecting regions: satellite observations and numerical simulations

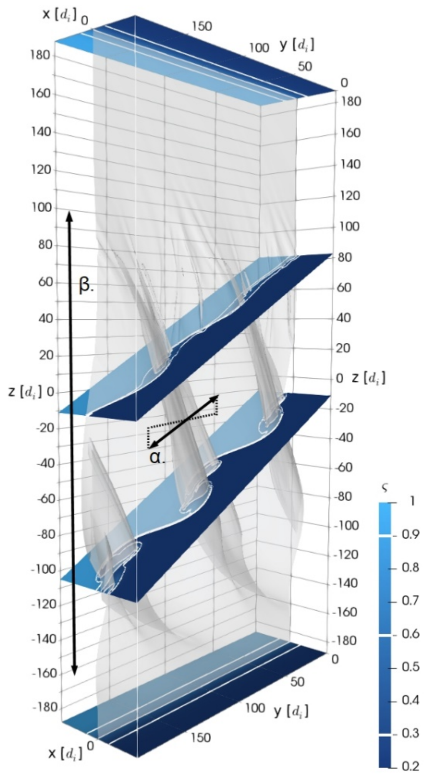
first part of the study nearly ready for submission

- We study the interplay of electromagnetic, kinetic and internal energies, the balancing of Euler's equation terms and those in Ohm's law, pressure agyrotropy and the local magnetic configuration
- We developed code to retrieve all a series quantities energy conversion rates from both MMS and simulation data (code available for all study groups in Toulouse and Pisa)
- Statistical analyses can also be performed, both on simulations and on MMS data (ISSI team collaboration!)



Meetings, workshops, schools

San Antonio : SWT (MMS) winter meeting 2018
Cargèse : Russian-French collaboration workshop
Toulouse : FPI meeting-workshop
Bergen : SWT (MMS) summer meeting 2018
Bern : meeting of ISSI team 2018
Washington : AGU fall meeting 2018
Rome : CINECA parallel computing summer school 2019
Bern : meeting of ISSI team 2019
Biarritz : SWT fall meeting 2019 (planned)



Collaborations

Marseille [M.Faganello] Latitude-wide magnetopause flank study
Exeter [R.Kieokaew] Curvature code benchmarking
Bern [ISSI team of G.Paschmann & T.Phan] Application of multi-satellite methods to current sheets from a large database
London [J.Eastwood] Joint work on energy conversion terms (?)

Energy densities and energy conversion rates in a turbulent, reconnecting plasma

S. Fadanelli, B. Lavraud, F. Califano et al.

(a computational study - sorry - but the code here is really nice …)

Idea: use simulations to retrieve patterns of energy densities and their changes

Which form for our equations?

[Birn & Hesse, 2010]

$$\partial_t K_s + \boldsymbol{\nabla} \cdot [\mathbf{u}_s K_s] = \boxed{- \mathbf{u}_s \cdot \boldsymbol{\nabla} \cdot \mathbf{P}_s} + q_s n_s \, \mathbf{u}_s \cdot \mathbf{E}$$

$$\partial_t U_s + \boldsymbol{\nabla} \cdot [\mathbf{u}_s U_s + \boxed{\mathbf{u}_s \cdot \mathbf{P}_s]} = \boxed{+ \mathbf{u}_s \cdot \boldsymbol{\nabla} \cdot \mathbf{P}_s} - \boldsymbol{\nabla} \cdot \mathbf{Q}_s/2$$

$$\Updownarrow$$

[Yang et al., 2017]

$$\partial_t K_s + \boldsymbol{\nabla} \cdot [\mathbf{u}_s K_s + \boxed{\mathbf{u}_s \cdot \mathbf{P}_s]} = \boxed{+ \mathbf{P}_s : \boldsymbol{\nabla}\mathbf{u}_s} + q_s n_s \, \mathbf{u}_s \cdot \mathbf{E}$$

$$\partial_t U_s + \boldsymbol{\nabla} \cdot [\mathbf{u}_s U_s] = \boxed{- \mathbf{P}_s : \boldsymbol{\nabla}\mathbf{u}_s} - \boldsymbol{\nabla} \cdot \mathbf{Q}_s/2$$

Back to the textbook

change along trajectory — compressions — pressure work — electric work

$$d_t K_s := [\partial_t + \mathbf{u}_s \cdot \boldsymbol{\nabla}] K_s = -K_s \, \boldsymbol{\nabla} \cdot \mathbf{u}_s - \mathbf{u}_s \cdot \boldsymbol{\nabla} \cdot \mathbf{P}_s + q_s n_s \, \mathbf{u}_s \cdot \mathbf{E}$$

$$d_t U_s := [\partial_t + \mathbf{u}_s \cdot \boldsymbol{\nabla}] U_s = -U_s \, \boldsymbol{\nabla} \cdot \mathbf{u}_s - \mathbf{P}_s : \boldsymbol{\nabla} \mathbf{u}_s - \boldsymbol{\nabla} \cdot \mathbf{Q}_s / 2$$

pressure work — heat exchange

Our analysis

#1: which effective sources??

change along trajectory | compressions | pressure work | electric work

$$d_t K_s := [\partial_t + \mathbf{u}_s \cdot \boldsymbol{\nabla}] K_s = -K_s\, \boldsymbol{\nabla} \cdot \mathbf{u}_s - \mathbf{u}_s \cdot \boldsymbol{\nabla} \cdot \mathbf{P}_s + q_s n_s\, \mathbf{u}_s \cdot \mathbf{E}$$

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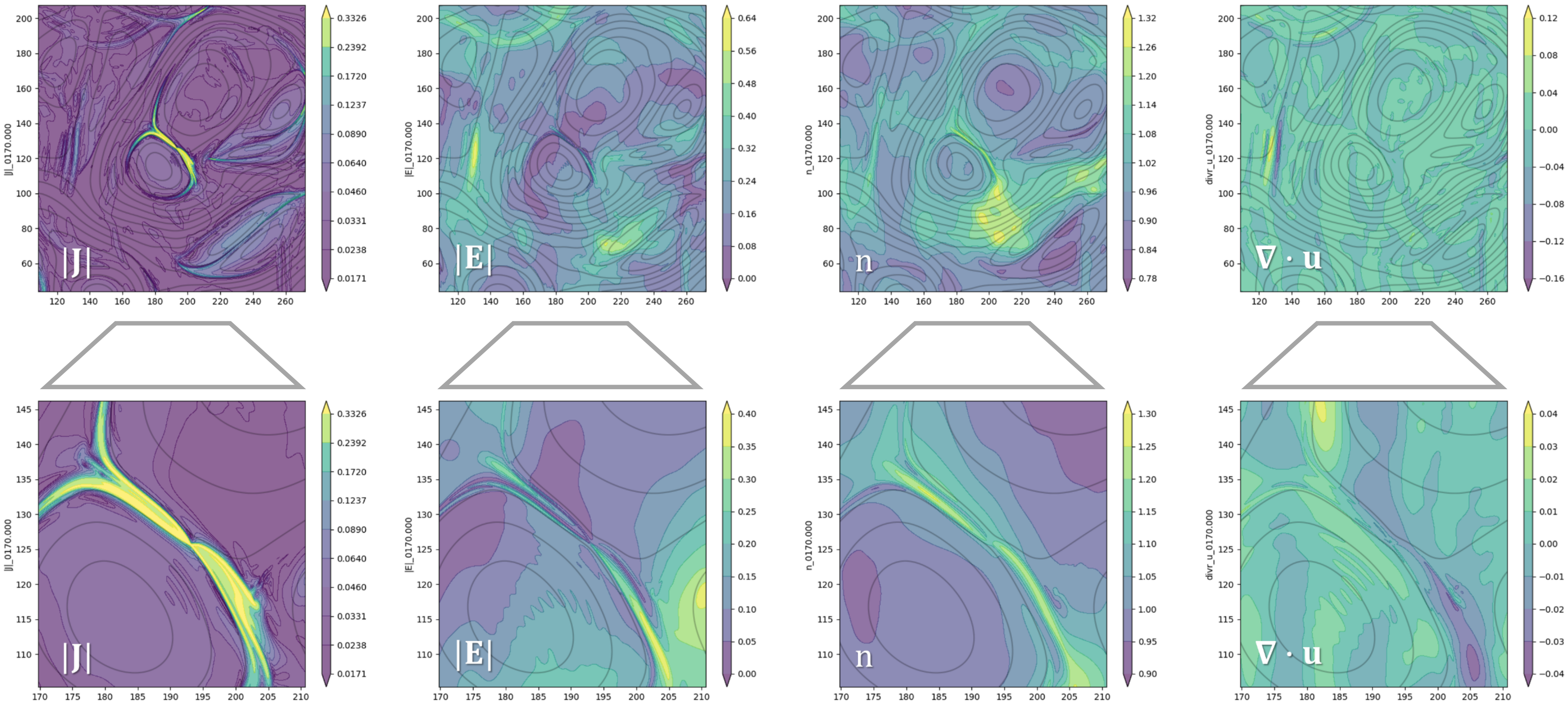
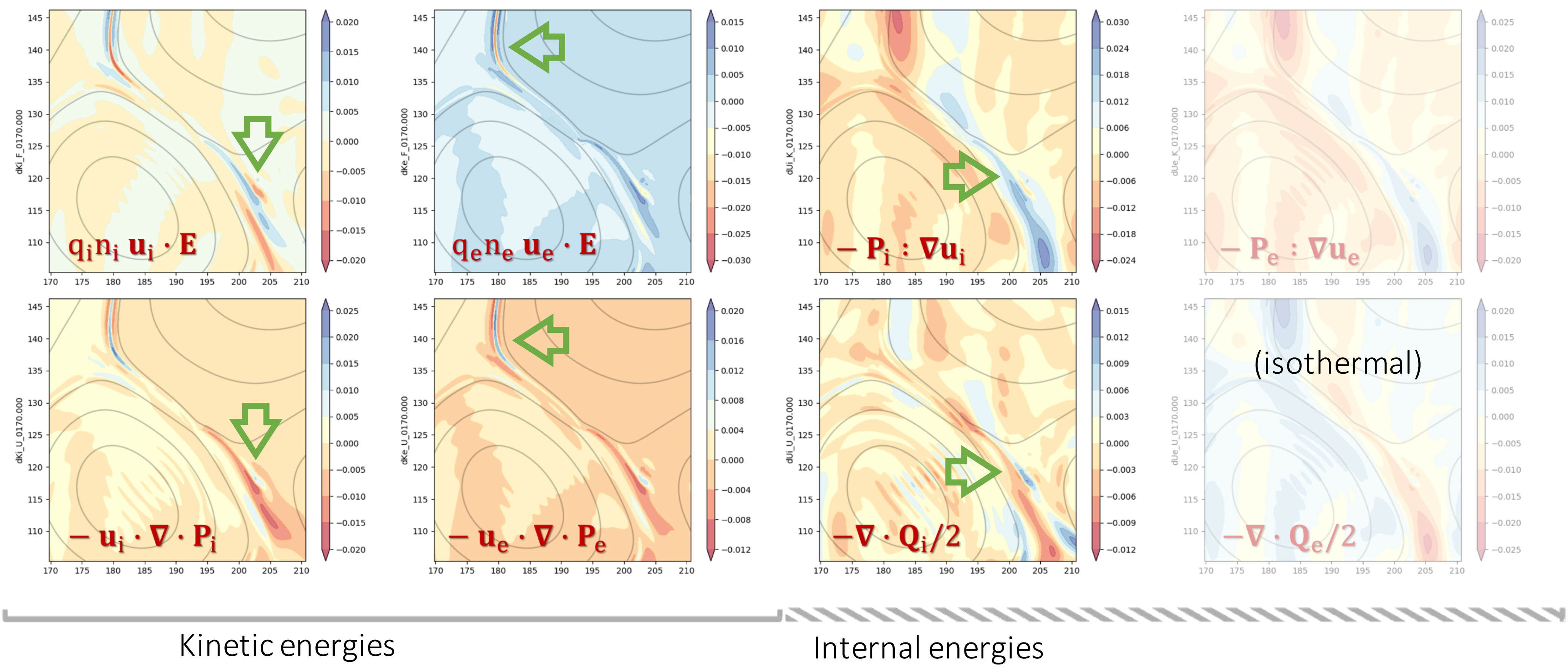
pressure work | heat exchange

#2: which spatial patterns??

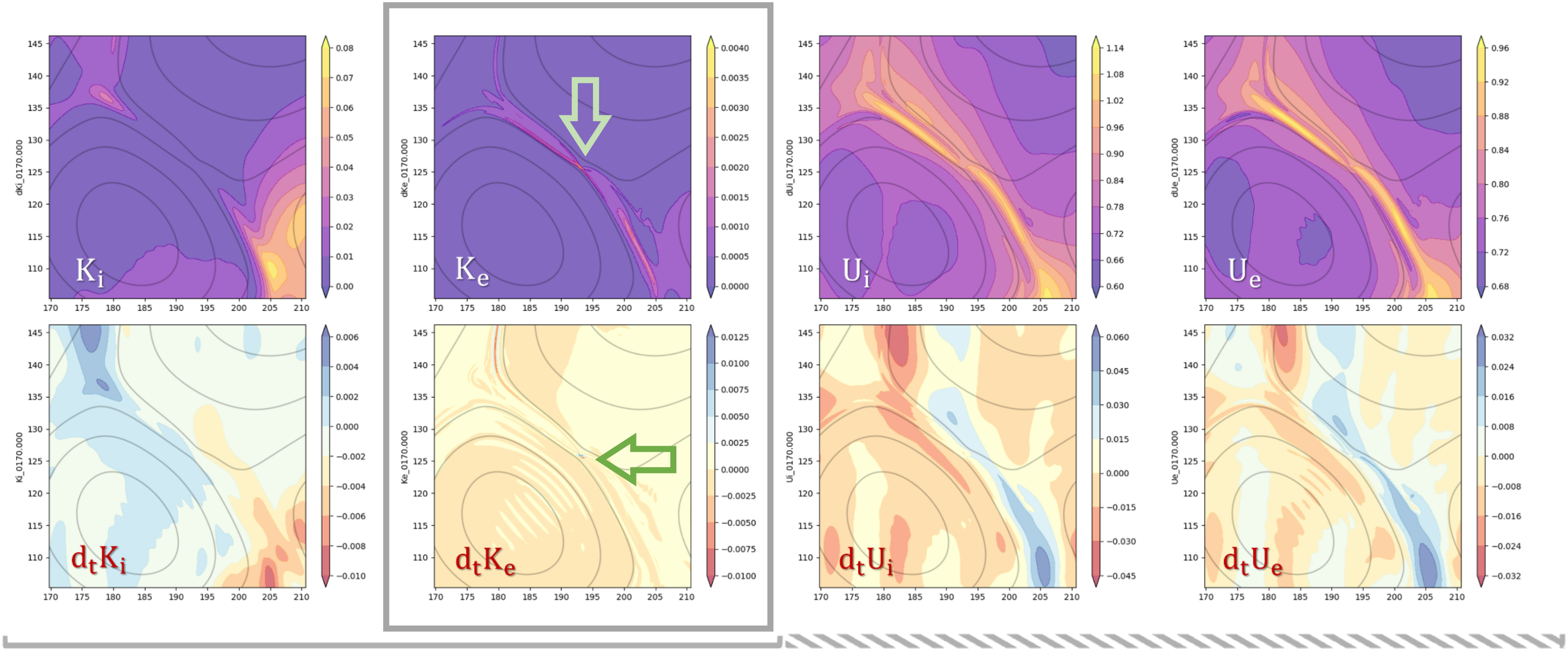
Our simulation: 2D - kinetic ions and fluid, isothermal electrons



#1: effective sources: energization from breaking of approx. balances



#2: spatial patterns: K_e responsive to small scales – K_i, U_i, U_e to large ones



Kinetic energies

Internal energies

Done but not shown

- single-fluid energy conversions (confront with older works)
- parallel/perpendicular decomposition ($K_{e\parallel}$ is the only relevant parallel component)
- sums over volumes

Planned work

- more realistic electron closure (CGL, LF …)
- 3D instead of 2D (less constraints, no artificial increase/reduction of some effects)
- confront with MMS (only way to verify these predictions)

Problems

- how do I measure effective correlation? (… scatterplots)
- how do I measure scale of perturbations? (… more scatterplots)

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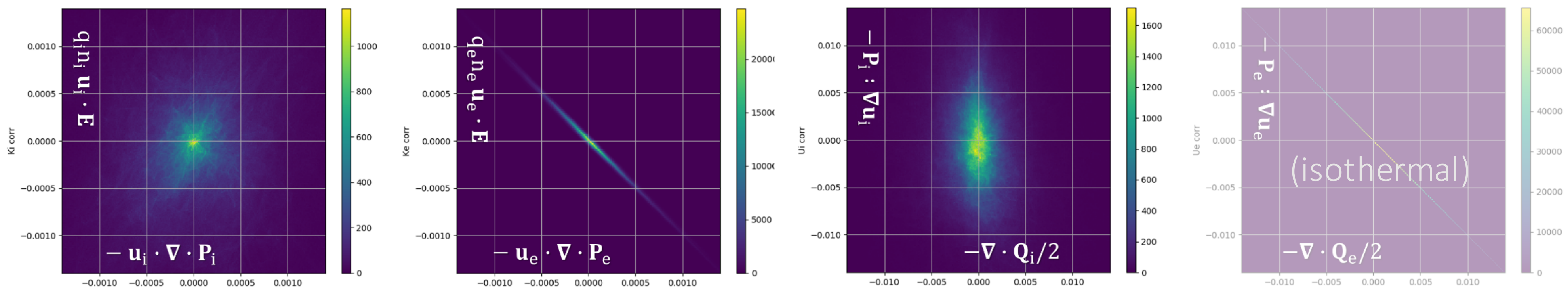
THANKS!!

Energization happens where perturbations can break approximate balances.
Different species respond at different scales (spatial and temporal),
hence they react to different perturbations and display different energization patterns

P.S. be careful when you estimate energy transfers:
terms you forget might balance the ones you have considered

How do I measure effective correlation? … scatterplots / combination of terms …



… and in 3D it actually works (!? … higher energization …)